SCIENCE FOR GLASS PRODUCTION

PROSPECTS OF A NEW METHOD
FOR THERMAL TREATMENT OF SHEET GLASS

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The essence of pulse hardening of sheet glass is considered and the results of a three-stage pulse hardening of sheet glass with a shrinking polymer film, are given.

The main techniques of heat treatment of sheet glass (annealing and hardening) are well mastered by the industry, regulated by the current standards, and ensure getting the prescribed properties in the product.

The general drawbacks resulting from this type of heat treatment are also known: relatively low strength of annealed glass and self-sustained (explosive) nature of hardened glass. The first defect entails elevated cost of building glazing due to a high amount of cullet (according to some data up to 30 – 40%), and the second defect prevents using hardened glass in laminar structures regulated by GOST 51136–98, which have greater thickness and, accordingly, weight than ordinary glass. These drawbacks lead to larger production volumes for sheet glass manufacturers; however, it is necessary to develop new types of products with alternative properties.

Such lines of research include complex thermal treatment, whose main principles were first discovered when working with new computer programs calculating internal stresses in sheet glass and later corroborated under laboratory conditions [1, 2].

The research was carried out in relation to the erroneous concept of I. A. Boguslavskii on the ratio of surface σ_s to central σ_c stresses in hardened glass represented by the parameter

$$\chi = \left| \frac{\sigma_s}{\sigma_c} \right|.$$

According to the data of I. A. Boguslavskii [3], an increase in the intensity of hardening, other terms being equal, results in a continuous increase in the parameters χ depending on the Biot number; however, the experimental data of other prestigious authors (R. Gardon, E. Mikhailick, S. Olberg, M. Takatsu, I. Vatanabe) and the calculated values obtained based on our method and converted to a single plot showed that the said statement has not been substantiated. We found a weak-extremum type of variation of $\chi = f(\text{Bi})$ with a maximum $\chi = 2.7$ in the range of Bi ≈ 1 [4].

This suggested that a cardinal modification of the hardening stress epure based on the traditional methods of heat treatment is impossible.

The main theoretical principle of the new approach to heat treatment of sheet glass is the assumption that it is possible to modify the internal stress epure and, accordingly, the properties of the product by nonstationary cooling of glass with sharply variable values of the heat transfer coefficient α.

First, pulse hardening was proposed (RF patent No. 2151750) with the maximum possible level α_{max} at the first stage of heat treatment, later changing to natural convection cooling $\alpha_{n.c}$ (Fig. 1). The duration of intense cooling $\tau_{i.c}$ proposed in the above-mentioned patent depends on the glass thickness and the purpose of the product and encompasses the range of 0.1 – 3.0 sec. The accomplished results showed the actual possibility of obtaining new consumer properties in glass, since due to a cardinal decrease in the central stresses level the tendency of the product to self-sustained destruction in the articles decreases until the glass can undergo machine treatment, and the high level of surface stresses ensures the elevated strength of the glass.

The study of pulse hardening revealed as well the negative side of the process: its excessively long duration, as a consequence of low intensity of glass cooling at the second stage. Therefore, a three-stage cooling scheme was chosen for later studies (Fig. 2). According to this scheme, $\tau_1 = \tau_{i.c}$

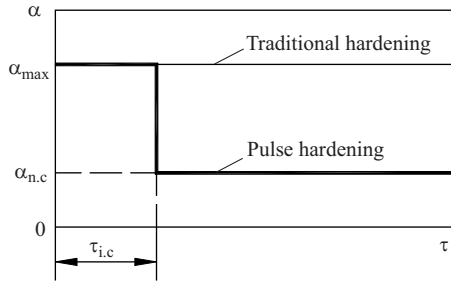[1] Belgorod State Technological Academy of Construction Materials, Belgorod, Russia.

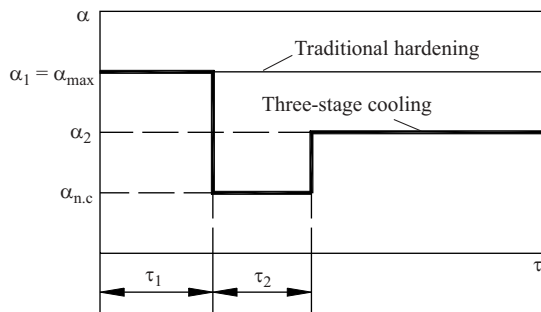**Fig. 1.** General scheme of implementation of pulse hardening.

Fig. 2. Three-stage cooling scheme.

Fig. 3. The effect of the surface stress level on the depth of break-through by a sphere: *1*) $\sigma_s = 0$; *2*, *3*, *4*, *5*, *6*, and *7*) $\sigma_s = 20, 40, 60, 80, 100$, and 120 MPa, respectively.

in pulse treatment, whereas the time τ_2 and the cooling intensity α_2 are selected to minimize the duration of chilling the article to an acceptable level while preserving the maximum value of χ, which determines the new consumer properties of the glass. In this case the surface stress level, which is responsible for the glass strength depending on the particular technological parameters, the main of which are the glass thickness and α_{max}, can reach 100 MPa and even more.

To estimate the efficiency of using glass with new properties, a method was developed involving the calculation of the penetration depth of an impact body (a sphere, a bullet) into a laminated glass article [5]. In particular, according to GOST R 51136–98, safe laminated glass with the degree of protection A1 for construction purposes is produced using the scheme $3 + 3 ++ 3$ (where 3 is the glass layer thickness and the symbol "+" indicates the presence of an adhesive polymer film of thickness 0.38 mm).

The strength testing of such articles is carried out by the impact performed by a sphere of diameter 100 mm (weight 4.11 kg) dropped from a height of 3.5 m. The research investigated the conditions for breaking through multiple glass consisting of annealed glass panes (the traditional variant) or glass after complex thermal treatment with the surface stress level varying from 20 to 120 MPa (Fig. 3).

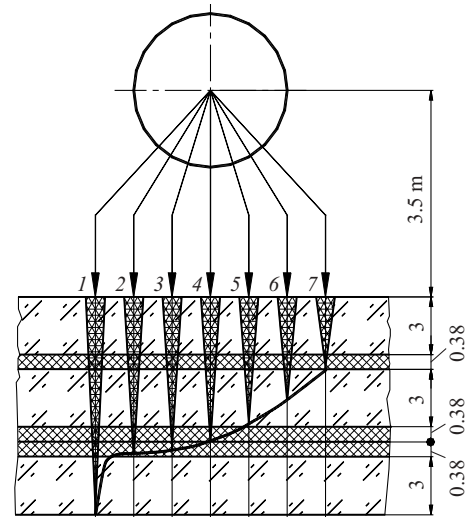In the initial variant the sphere becomes "suspended" in the last layer, which is required by the current standard. At the same time, the depth of penetration into laminated glass perceptibly decreases with increasing surface stresses. Thus, with $\sigma_s = 80$ MPa, the degree of protection A1 can be preserved without including the bottom glass layer and two layers of PVB film in the multiple-glass packet.

There are data on other combinations of multilayer products, including bullet-proof glass articles.

The new principle of producing multilayer glass products will allow for substantial savings in materials and energy and will reduced the expense involved in importing film, while the required level of safety in products will be preserved.

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